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RELIABILITY ANALYSIS OF THE

MARINER C SPACECRAFT

PRC R-433

9 December 1963

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Prepared for

Jet Propulsion Laboratory
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By

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ABSTRACT

A study of the Mariner C spacecraft has resulted in a predicted probability of 0.15 of successfully transmitting the encounter TV science data to earth, considering catastrophic failures and operational effects when using the planned sequence of events. Redundancy in the system which provides alternate sequences in case of failure raises the probability of success to 0.18 for the encounter TV. Similar numbers are derived for the secondary objectives. The study concludes that by making three hardware changes to provide a redundant star tracker, redundancy in the CC and S, and a separate encounter encoder, the probability of success can be raised to 0.5.

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LIST OF EXHIBITS

I. INTRODUCTION

A. Contract Requirements

On October 17, 1963, a contract was awarded to Planning Research Corporation by the Jet Propulsion Laboratory of the California Institute of Technology for the purpose of performing a logical and functional study of the Mariner B spacecraft. The contract, No. 950759, is a subcontract under NASA contract NAS7-100.

This report is in response to paragraph (a)(4)(i) of the contract, which calls for a progress report on the work performed under paragraphs (a)(1)(i) through (a)(1)(iii). The work performed under these three paragraphs will be referred to as Tasks 1, 2, and 3.

B. Tasks 1, 2, and 3

The contract requires the performance of a logical and functional study of the Mariner B spacecraft bus and its mission, based upon a logical and functional analysis of Mariner C.

Seven tasks are included, and the first three reported on here are as follows:

Task 1. Formulate a method of approach to the logical and functional analysis of a spacecraft bus and its mission.

Task 2. Use the approach developed under Task 1 to assess the capability of Mariner C to fulfill its mission. This assessment shall include consideration of the relative importance to the mission of the spacecraft functions, and the capability of the subsystems to perform these functions in a reliable manner.

Task 3. Suggest modifications toward optimization of Mariner C design and flight sequence relative to mission objectives, including reliability.

C. Study Constraints

The contract restricted the study to the portion of the mission beginning with the spacecraft separation from the launch vehicle and continuing for the spacecraft's useful life. In addition, minimum changes

in the subsystems are to be made. For the purpose of this study the spacecraft's useful life ends at the end of transmission of the Mars encounter data.

D. Study Plan

The three tasks outlined above form the preparation for the remaining tasks (4 through 7) which cover the Mariner B. In Task 1 a methodology is required which can be used for the evaluation of a spacecraft design. The methodology and evaluation are based on predicting the probability of the spacecraft's accomplishing the objectives of a mission, considering catastrophic failures of equipments. Performance evaluation and environmental influences are beyond the scope of the contract, although the influence of performance and environment has been included in a few instances where information was available.

The methodology developed under Task 1 was used to evaluate the reliability of the Mariner C design and later will be used to evaluate a B design and to compare the two designs.

Task 2 required detailed analysis of the spacecraft's operation and computation of the probabilities of attaining the objectives, based on a knowledge of the failure rates of the equipment component parts. This information was available from a previous study made by Planning Research Corporation under contract with the Jet Propulsion Laboratory. The previous study had also developed reliability diagrams which showed the series and parallel paths of the equipments. In Task 2 this previous information was used to compute the probability of attaining the objectives when using a particular sequence of events. Various sequences were examined, including the normal or planned sequence and alternates that could be used in case of failure.

In Task 3 the results of Task 2 were examined, and recommendations for improvements were developed.

In the previous study of Mariner reliability by PRC, a figure-of-merit was determined based on the estimated worth of data and the probability of obtaining the data. In this study the figure-of-merit was not used. The probabilities of obtaining five stated objectives were

calculated. These probabilities, together with an estimate of the relative worth of the objective, could be used to determine a figure-of-merit.

E. The Mariner C and B

The mission of the Mariner C and B spacecraft is to provide close observations of the planet Mars and information significant to the determination of the existence of life on Mars.

A primary objective of Mariner C is a close flyby of Mars and the transmission to earth of a TV picture and spectrometer data. Of secondary importance is science data measured during the long cruise to Mars and engineering data on the spacecraft's operation. In performing the present study, the primary objective of obtaining the science (TV and spectrometer) data at encounter with Mars has been used as a criterion for judging a sequence to be useful and worthy of examination.

The Mariner C launchings will take place in the 1964 time period. The B launchings will be in 1966. An instrument capsule will be launched from B near encounter to enter the atmosphere and land.

F. Report Organization

The report is organized on a task basis, with three sections following this introduction. Task 1 is covered in Section II. The methodology used in the study is described in this section.

Task 2 is covered in Section III, where the numerical assessment of Mariner C is described.

Task 3 is covered in Section IV, which provides the conclusions and recommendations of the report.

II. TASK 1--METHODOLOGY

A. Task Definition

The development of a method of approach to be used in the functional and logical analysis of a spacecraft bus and its mission is the problem of Task 1. The method developed has to some extent been employed in past studies made by PRC for the Mariner spacecraft and two of its missions (Venus flyby and Mars 1964 flyby). The current study, however, requires significant additions and changes to the method used previously.

The previous study of the Mariner C determined the reliability of components and subsystems for the long flight to Mars, the probability of attaining all objectives with redundant paths assumed, and a figure-of-merit based on a set of objectives different from those presently used. The present study determines the probability of attaining the primary and secondary objectives when using the current updated sequence of events and when using alternate sequences which will result in meeting the primary objectives when a failure occurs.

The methodology is outlined in ten steps in broad terms without specifying how each step is to be performed. Application can be made to both the Mariner C and B and in general to any system.

B. Methodology

1. Determine the mission objectives and the relative weights or importance of objectives. These objectives must be of the type whose accomplishment depends on the successful operation of an equipment (or equipments) that can be described in hardware terms. The relative weights may be simple (constants) or more complex (value functions required for PRC's figure-of-merit model).

2. Determine a sequence of events to meet the objectives.

3. Determine the subsystems and subsystem equipment needed to achieve each objective and the time of operation of each equipment. A reliability block diagram of the equipment may be used to show the

series and parallel paths. The subsystems of the spacecraft are sufficiently complex that several diagrams may be required for each objective. Some diagrams, however, may be common to one or more objectives.

4. Write the probability equations for attaining each objective. These are the reliability equations, and steps 2 and 3 enter into their formulation.

5. Assign the failure rates and calculate the reliability of the equipment required for attaining each objective. Failure rates are determined on a component basis, and the probability number for groups of these components which make up each block in the reliability diagrams is required.

6. Using the equation of step 4, compute the probability of meeting an objective. This step simply applies the results of step 5 to the equations of step 4 for each of the objectives of step 1.

7. If desired at this step, compute the figure-of-merit for each objective and the overall mission. This is a process of combining the probability of achieving an objective with its relative weight in the overall mission. The figure-of-merit for the overall mission will provide one means of comparing sequences. This step, however, was omitted in the present study.

8. Determine new sequences by examining the effects of failures of subsystems and freedom of choice of commands. The determination of new sequences by examination of freedom of choice of events could also be made at this step.

9. Repeat steps 3 through 7 for each new sequence. The number of new sequences is not expected to be high, because of the number of constraints, i.e., configuration of equipment, weight, etc.

10. Compare sequences and recommend preferred sequences and design changes. Engineering judgment, together with the reliability numbers, contributes to this step.

C. Application

In the following section, the methodology is applied to Mariner C. The assumptions and results are included, with the detailed arithmetic calculations and the equations omitted. All of the steps of the methodology except 7 and 10 have been used and are included in Section III. Step 10 is in essence Task 3, which is covered in Section IV. The equations that apply have been detailed in the prior study and are reported in the interim report of that study (PRC R-322).

III. TASK 2--NUMERICAL ASSESSMENT

A. Method of Approach

1. Objectives Selected

As described in the general methodology presented in Section II, this numerical assessment is made to give a quantitative measure of the design of the Mariner C spacecraft from a reliability viewpoint. Probabilities in the classical reliability sense are developed for the Mariner C mission as defined by five objectives. These five, stated in terms of data transmitted, are as follows:

Primary objectives
- Encounter science--TV
- Encounter science--UV

Secondary objectives
- Cruise science during cruise
- Cruise science during encounter
- Engineering up to encounter

In addition, a final evaluation encompassing all five objectives is given. Each of these is assessed under (1) the planned sequence of events and hardware configuration and (2) three alternate sequences and hardware configurations in the event of certain subsystem failure.

It should be noted that this assessment of the Mariner C spacecraft differs from an earlier assessment made by PRC and reported in PRC R-362.[1] In the prior assessment emphasis was placed on the use of PRC's figure-of-merit model. This is a technique which, by introducing the concept of worth accrual as a function of time, affords a means of accounting for the partial success that might well be achieved in a mission where some degradation of performance has occurred because of an impairment which is not totally catastrophic. This assessment,

[1] Planning Research Corporation, PRC R-362, The Reliability Assessment of the 1964 Mariner Mars Spacecraft, 22 July 1963.

by request of the Systems Division of JPL, departs from that model in that no worth assignments are made, and not all degraded paths are considered. The probabilities developed reflect the constraint that a specific set of hardware operate for a given time to accomplish a mission objective: failures are catastrophic.

2. Planned Sequence

The Planned Sequence is adapted from the latest available JPL publication.[1] For calculation purposes, a total mission length of 6,213 hours is assumed, with 6,000 hours to encounter. These are the same values as used in the prior study.

Exhibit 1 shows the event list used in the calculations and the time at which each event is assumed to occur. In general, the hardware configuration considered requires all subsystems of the spacecraft to be operating when needed, but without the use of the backup capability of the radio-command subsystem. Any redundant equipment not requiring ground commands (for example, the internal switching of the transmitter) is included. Complete details of hardware and operating time are given below in the development of the probability that each objective is met under these conditions (Subsection C).

Exhibit 2 lists the subsystems into which the spacecraft has been divided. They are defined in this manner for ease in calculation and analysis. For example, the attitude control subsystem is divided into four "subsystems" on the basis of functions performed. An examination of the subsystems of Exhibit 2 reveals three subsystems which can incur a failure and for which an alternate sequence and hardware configuration can be used to meet the five objectives. Failure of any other subsystem causes loss of the primary objectives. Three of the five objectives involve an encounter. Those degraded states which result in obtaining cruise science data and engineering data but which do not result in

[1] Jet Propulsion Laboratory, Spec. No. MC-4-180A, Functional Specification Mariner C Flight Equipment Flight Sequence, 27 September 1963.

EXHIBIT 1 - PLANNED FLIGHT SEQUENCE

	Event	Time	Cumulative Time (hours)
1.	Injection--Deploy Solar Panels	t_0	
2.	Begin Sun Acquisition	t_1	
3.	End Sun Acquisition	t_2	0.5
4.	Turn on Solar Stabilization System	t_3	16
5.	End Canopus Acquisition	t_4	17
6.	Begin Data Insertion	t_5	24
7.	End Data Insertion	t_6	25
8.	Begin Midcourse Maneuver	t_7	41
9.	End Midcourse Maneuver	t_8	43
10.	End Sun Acquisition	t_9	43.5
11.	End Canopus Acquisition	t_{10}	44.5
12.	Second Maneuver Omitted	$t_{11}-t_{16}$	288
13.	Switch Bit Rate	t_{17}	1392
14.	Set Canopus Sensor Cone Angle 1	t_{18}	2712
15.	Transmitter Low-Gain Antenna Limit	t_{19}	2376
16.	Transfer to Transmit Via High-Gain Antenna	t_{20}	2856
17.	Set Canopus Sensor Cone Angle 2	t_{21}	3528
18.	Half-Power Transmitter Limit	t_{22}	4248
19.	Set Canopus Sensor Cone Angle 3	t_{23}	4368
20.	Set Canopus Sensor Cone Angle 4	t_{24}	5280
21.	End Cruise	t_{25}	5950
22.	Begin Encounter	t_{26}	5993
23.	Closest Approach	t_E	6000
24.	End Encounter	t_{27}	6006
25.	Begin Playback	t_{28}	6013
26.	End Playback	t_{29}	6213

EXHIBIT 2 - SUBSYSTEMS

Attitude Control Solar Vanes (P, Y, R jets)

Attitude Control Sun Acquisition and Tracking

Attitude Control Star Acquisition and Tracking

Roll Jets

Central Computer and Sequencer

Power Through Midcourse

Power Encounter and Cruise

Power Cruise

Radio Receiver

Decoder

Encoder

Transmitter

Planetary Instrument Scan

Propulsion

Tape Recorder

obtaining encounter data are not considered in this study. Failure to perform the midcourse correction, for example, would still permit the two cruise objectives but would prohibit attaining the three encounter objectives.

3. Alternate Sequences

a. Loss of the Star Tracker

In the event that a failure occurs such that Canopus cannot be tracked, an inertial roll capability has been provided in the Mariner C design. In the probabilities calculated below, it is assumed that all subsystems must operate through the reacquisitions after midcourse maneuver. Then, at any time after t_{10} and before t_{25} (see Exhibit 1) this sequence requires the equipment of the inertial roll control mode to be operable for 26 hours; after t_{25}, it is required for 263 hours. The 26 hours is an assumption which, in the event of star tracking failure, allows for the operation of the inertial roll control for inflight checkout to align the high-gain antenna and transmit data. Except for the short checkout time, the spacecraft would be allowed to drift in roll until 50 hours prior to encounter. From t_{25} until the end of playback, the system must be operable. All other subsystems of Exhibit 2 are required in a series manner. Details of hardware and operating time required are given in subsection D.

b. Loss of PNG/ADC Units of the Encoder

In the series circuits and analog-to-digital converter of the encoder subsystem, a mode of operation is available in the event of failure in the pseudo-noise generator and analog-to-digital converter. The redundant mode is a switchable redundancy, requiring DC-6 to start the spare equipment. In this alternate sequence, then, it becomes necessary that the radio receiver and decoder series units be available. All other subsystems are required to operate as in the Planned Sequence.

c. Loss of the CC and S

The Central Computer and Sequencer is required for all modes of operation considered in this report through midcourse maneuver. The radio-command subsystem is also required, since there is no other way to signal maneuver start. After midcourse maneuver, however, the

radio-command may be considered as a backup to master-timer signals from the CC and S.

The probabilities of meeting each objective in this alternate sequence are computed in two ways. First the radio-command subsystem after midcourse maneuver is computed as redundant to the CC and S. This includes the radio receiver and command series units through the remainder of the flight, together with the peculiar hardware for eight commands given at the time the corresponding CC and S signal is required. Additional probabilities are shown, given that the CC and S fails at a specific time during cruise up to encounter, that the radio-command subsystem will remain operable so that the objectives are met. Five specific times of failure of the CC and S are selected.

B. Assumptions

It is important to state the explicit assumptions that have been necessary to place reasonable bounds on the scope of the study in addition to those already mentioned. Many implicit assumptions are made in the model representation, i.e., the reliability block diagrams; these are discussed in the subsystem descriptions of PRC R-362.[1] Some of the following assumptions were also made in that earlier report; all apply to this study.

1. Scientific experiments are completely reliable. Except for certain hardware associated with the planet scanning function, it is assumed that none of the scientific experiments fail during the mission.

2. Engineering measurement transducers are completely reliable. This is similar to assumption 1, but refers to the equipments (such as temperature or position transducers) that provide the unconditioned signals for telemetry purposes.

3. The trajectory of the space probe after injection is correctible by one midcourse maneuver. The assumption that only one midcourse correction will be needed is justified on the basis that the probability of needing the second correction has been shown to be sufficiently small (PRC R-362). This also simplifies many of the calculations and is actually the nominal plan of operation.

[1] PRC R-362, Section III, pp. 9-9[illegible].

4. The mission period is 6,213 hours. This variable, which depends to a large extent on the time of launching, has been fixed at 6,213 hours. This places the time of closest approach at 6,000 hours after injection.

5. Part failures are catastrophic. Degraded operation of piece parts is not considered. It is assumed that a failed part is completely inoperable and will remain inoperable from the time of failure throughout the balance of the mission.

6. Part failures are random in time. This assumption is predicated on the absence of "burn-in" or "wear-out" failure mechanisms, and allows the application of the exponential failure law and the exclusive use of random failure rates.

7. All parts are exposed to the same stress. The selected failure rates are based on the assumption that each piece part is stressed to 25 percent of its design rating and operates in an unchanging ambient temperature of 35°C.

8. Piece-part and unit failure rates. The failure rates used for component parts and for the reliability units are the same as those developed in PRC R-362.[1]

9. DAS. The reliability of the DAS is omitted, since the design data was unavailable for this study.

10. Operational probabilities. In the earlier assessment, five operational probabilities were included in the calculations. Each of these is necessary in a total reliability assessment and can influence the design of equipment. It is also recognized, however, that they are different from the probabilities describing hardware failures. For this reason, the calculations of this study have been performed with these probabilities both included and excluded. The five in question are as follows:

a. Probability of no meteor impact. An estimate of 0.9 has been made for this. The equipment needed to reacquire after such an impact forms a simple redundant path to the probability that no impact occurs. The probability that a recovery is made with one impact is 0.969. This calculation includes an operational probability that the

[1] PRC R-362, pp. 3, 4; 96-111; Appendix A, pp. 167-239; Appendix B, pp. 243-248.

wrong target is not acquired; if this is excluded, the probability of reacquiring becomes 0.977. These numbers do not appear in the tables below.

b. Probability of solar panels not degrading. An assumption has been made that there is a possibility that the solar panels will degrade to an extent that the operation of the battery share protector and the battery may be required to furnish power at encounter. A probability of 0.75 that the solar panels will not degrade to this extent was previously agreed to by both PRC and JPL as a reasonable assumption. This has been included in the calculations; the tables also show the effect of eliminating this assumption. It should be pointed out, however, that the removal of this redundant path[1] removes any consideration of the reliability of the solar panels. The solar panel circuitry is included (unit 501), but the solar panel reliability enters as 1.0.

c. Probability that wrong target is not acquired. The number assumed here is 0.9. Again, the tables of this study show the reliability of the star tracker both with and without this assumption.

d. Probability of adequate first maneuver. This probability, 0.9782, resulted from a study by JPL and accounts for the accumulation of errors even though no equipment failure is experienced.

e. Probability of adequate second maneuver. Second maneuver possibility is omitted from all calculations.

Again, PRC feels that probabilities of a, b, c, and d are vital to a reliability assessment; the differences in the calculations resulting from not using b, c, or d are indicated. The meteor correction probability is treated separately.

11. Single subsystem failures. As discussed in subsection A, it was determined that only three subsystems of Exhibit 2 could incur failures such that an alternate sequence could be defined to achieve the five objectives. The probabilities tabulated in the subsequent subsections allow only one of these three failures to occur at a time.

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[1] PRC R-362, Exhibit 30.

C. Planned Sequence

1. Problem

The probabilities of achieving each of the five objectives are computed, given the planned sequence of events and each subsystem performing as designed. Radio commands are considered as a backup function and therefore do not enter into any of the calculations.

2. Assumptions

No assumptions in addition to those of subsection B are required.

3. Calculations

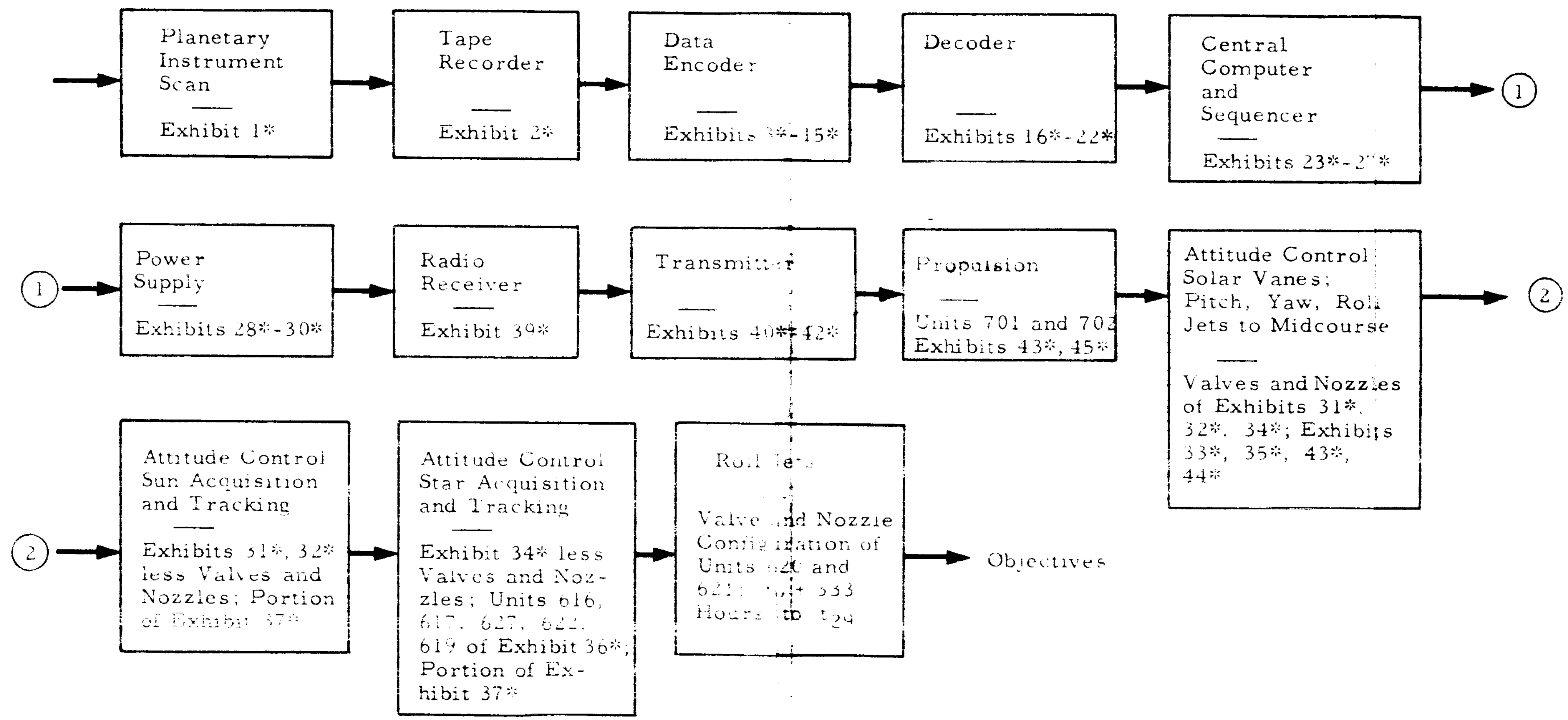
Exhibit 3 shows the reliability block diagram applicable to this sequence. All exhibit numbers followed by an asterisk refer to those in PRC R-562. The specific units of each subsystem that are required and their operating times are detailed as follows for each of the five objectives and the composite "all objectives."

a. Encounter Science--TV

(1) Attitude control solar vanes (P, Y, and R jets). All units of Exhibits 33* and 35* and the valve and nozzle configuration of Exhibits 31*, 32*, and 34* are required until complete stabilization is achieved. This time is estimated to be 333 hours after t_9.

(2) Attitude control sun acquisition and tracking. This subsystem is not required after reacquisition following midcourse maneuver. The following units are used:

Units	Time Required
Exhibit 31*	
601 and L-2 redundancy	t_1
602, 603, 605, 611	$t_0 - t_9$
509, 510, 511, 513, 606, 607, 608	$t_1 - t_2$, $t_8 - t_9$
redundant 610	$t_0 - t_9$



Note: Exhibit numbers followed by an asterisk refer to PRC R-56. No command backup is used.

EXHIBIT 3 - SUBSYSTEMS FOR PLANNED SEQUENCE

Units	Time Required
Exhibit 32*	
614	$t_2 - t_7$
605, 610, 611 included above	-
Exhibit 37*	
611 included above	-
Exhibit 43*	
901, · · ·, 910	$t_0 - t_1$
Exhibit 44*	
All units in redundancy shown	$t_0 - t_1$

(3) Attitude control star acquisition and tracking. This subsystem is required throughout the flight. The operational probability that a wrong target is not acquired is introduced. The objective probabilities are computed with and without unit 952 as discussed above. The following units are needed:

Units	Time Required
Exhibit 34*	
616, 617	t_4 - 1.0 hour to t_7, $t_9 - t_{29}$
606, 607, 618	t_4 - 1.0 hour to t_4; $t_7 - t_8$; $t_9 - t_{10}$
619	$t_0 - t_{29}$
952	-
Exhibit 36*	
616, 617, 619 included above	-
622, 627	$t_0 - t_{29}$
Exhibit 37*	
606, 607, 618, 619 included above	-
608	t_4 - 1.0 hour to t_4; $t_7 - t_8$
623	$t_0 - t_9$

(4) Roll jets. Units 620 and 621 are required from t_9 + 333 hrs to t_{29} in the redundant configuration as described in PRC R-362.[1]

(5) Central Computer and Sequencer. The CC and S is required to remain operable throughout the entire flight. Some units, however, are not required after a particular time; these are then dropped from the remainder of the calculations.

Units	Time Required
Exhibit 23*	
401, 402, 403	$t_0 - t_{29}$
405	$t_0 - t_3$
406, 406a included in sun acquisition and tracking	-
407, 407a included in sun acquisition and tracking	-
408 and 408a included in solar vanes	-
Exhibit 24*	
409, 410	$t_0 - t_6$
411, · · · , 416	$t_0 - t_8$
Exhibit 25*	
411, · · · , 416 included above	-
417, 418, 420, 424, 437, 439, 442, 444, 446	$t_0 - t_8$
448, 449, 451, 454	$t_0 - t_8$
419, 421, 422, 438, 440, 441, 447	$t_0 - t_7$
450, 452, 453, 455, 443, 438, 445, 441	$t_0 - t_7$
Exhibit 26*	
401, · · · , 403 included above	-
404, 425, 426	$t_0 - t_{29}$
427	$t_0 - t_{18}$

[1]PRC R-362, p. 138.

Units	Time Required
Exhibit 26* (Continued)	
428	$t_0 - t_{21}$
429	$t_0 - t_{23}$
430	$t_0 - t_{24}$
431	$t_0 - t_{20}$
432	$t_0 - t_{17}$
427a, · · · , 433a	one actuation each
Exhibit 27*	
401, · · · , 404 included above	-
425, 426 included above	-
434	$t_0 - t_{26}$
435	$t_0 - t_{27}$
436	$t_0 - t_{28}$
434a, · · · , 436a	one actuation each

(6) Power through midcourse maneuver. The power subsystem has two redundancies which are considered a part of planned operation. One, a simple redundancy, involves units 516 and 517, synchronous source transfer and L. C. oscillators. The second is a switchable redundancy involving the booster regulators, units 506 and 507, and the unit which is the switch, 515. This is not treated as a redundancy through midcourse maneuver, however. Booster regulator number 1 or 2 can supply the 2.4-kc main power, but booster regulator number 1 cannot supply the maneuver loads. Therefore, a failure in unit 507 would cause failure to perform the maneuver. The following units are required:

Units	Time Required
Exhibit 28*	
516 and 517, redundant	$t_0 - t_{10}$
501, · · · , 505	$t_0 - t_{10}$
507, · · · , 511, 513	$t_0 - t_{10}$

(7) Power during encounter and cruise. During cruise and encounter the booster units, 506 and 507, and the switch, 515 are a switchable redundancy. A solid line is shown in Exhibit 30* around unit 510, since the 400-cycle synchronization source is not absolutely necessary for the operation of the single-phase inverter. Therefore, booster regulator number 2 is not required at encounter; either booster can supply the encounter loads.

Units 516 and 517 remain in their simple redundant relationship. Unit 952 is the operational probability that the solar panels do not degrade to the extent that the battery and its share protector are needed for the encounter phase. Again, the objective probabilities are computed including and excluding this redundancy.

Unit 501, solar panel circuitry, is a complicated unit involving internal redundancies. It is included here as described in PRC R-362.[1] The following units are required for this subsystem:

Units	Time Required
Exhibit 29*	
501, 504, 505, 508	$t_{10} - t_{29}$
516, 517 redundancy	$t_{10} - t_{29}$
506, 507, 515 redundancy	$t_{10} - t_{29}$
Exhibit 30*	
951, 503, 502 redundancy	$t_{26} - t_{27}$
512	$t_{26} - t_{29}$
501, 504, 505 included above	-
516, 517 redundancy included above	-
506, 507, 515 redundancy included above	-
508 included above	-

[1] PRC R-362, p. 237.

(8) Radio receiver. The radio receiver is not required after midcourse maneuver; all radio commands after maneuver are considered as backup to the CC and S and are not a part of this sequence. The following units are involved:

Units	Time Required
Exhibit 39*	
807, 808, 809, 836, 810	$t_0 - t_8$

(9) Decoder. The decoder is not required after midcourse maneuver, just as the receiver is not. However, two commands are required for this sequence: QC-1 for data insertion prior to midcourse maneuver, and DC-27, the maneuver start command. The necessary units are, then:

Units	Time Required
Exhibit 16*	
3079, 3000, 3001-1, 3002, 3003	$t_0 - t_8$
Exhibit 22*	
3005, 3006, 3007	$t_0 - t_7$
All other units	$t_0 - t_6$
Exhibit 19*	
3005, 3006, 3007 included above[1]	-
3008-2, 3009, 3011, 3013, 3016, 3018	$t_0 - t_7$
3019, 3023*, 3078-1, 3078-2	$t_0 - t_7$

(10) Encoder. Those units of the encoder for this sequence do not include the spare PN generator. This is considered a

[1] Detailed block diagrams were not included in PRC R-362. It is stated there that DC-27 has the same configuration as Exhibit 19. The unit numbers used here may be found in the interim report, PRC R-322, 6 May 1963.

switchable redundant path, requiring a ground command. The required units are as follows:

Units	Time Required
Exhibit 15*	
All units except 2006, 2004-2, 2003-2	$t_0 - t_{29}$
Exhibit 12*	
Video data: no information	-
Exhibit 14*	
All units needed for cone angle updates	$t_0 - t_{24}$

(11) Transmitter. Both coherent and noncoherent transmission is permissible. The transmitter units are:

Units	Time Required
Exhibit 40*	
All redundant paths with or without VCO	$t_0 - t_{29}$
821	$t_0 - t_{29}$
Exhibit 41*	
All redundant paths	$t_0 - t_{29}$
804, 835	$t_0 - t_{29}$
Exhibit 42*	
837, 801	$t_0 - t_{19}$
802, 805	$t_0 - t_{29}$
804 included above	-

(12) Planetary instrument scan. The following are required for this subsystem:

Units	Time Required
Exhibit 1*	
Pyrotechnic units	$t_0 - t_{26}$
101, 102	one actuation
103, 104	$t_{26} - t_E$

(13) Propulsion. The propulsion subsystem is required through midcourse maneuver. The third operational probability, unit 952, is used. This is the probability of an accurate maneuver even if there are no equipment failures. Units required here are:

Units	Time Required
Exhibit 37*	
701	$t_0 - t_8$
702	one cycle
953	-
Exhibit 45*	
All pyrotechnic units (explosive valves, one actuation)	$t_0 - t_8$

(14) Tape recorder. There are three tape recorder units required, all shown in Exhibit 1*: 105 and 107 must operate between t_E and t_{29}; 106, from t_E to $t_E + 20$ minutes.

b. Encounter Science--UV

All units of the subsystems are required in the same manner as listed above for the first objective, except that the tape recorder subsystem is not required for this objective.

c. Cruise Science--Cruise

(1) The following subsystems are the same as those defined for encounter science--TV:

(a) Solar vanes
(b) Sun acquisition and tracking
(c) Power through midcourse
(d) Radio receiver
(e) Decoder
(f) Propulsion

(2) The following subsystems are not required:

(a) Planetary instrument scan
(b) Tape recorder

(3) Several subsystems differ from the requirements given in encounter science--TV only in length of operating time. For this objective, the star acquisition and tracking subsystem and the transmitter are not required after t_{25}; the CC and S drops out of the calculations after t_{24}.

(4) Power cruise. Since no encounter is required for this objective, the power subsystem reduces to power during cruise. The units are:

Units	Time Required
Exhibit 29*	
501, 504, 505, 508	$t_{10} - t_{25}$
516, 517 redundancy	$t_{10} - t_{25}$
506, 507, 515 redundancy	$t_{10} - t_{25}$

(5) Encoder. The transmission of cruise data requires a different configuration of the encoder. This is defined as:

Units	Time Required
Exhibit 12*	
2025, 2026 redundancy	$t_0 - t_{25}$
Exhibit 14*	
2023, 2020, 2019, 2018	$t_0 - t_{25}$
Exhibit 15*	
All units except 2006, 2004-2, 2003-2	$t_0 - t_{25}$

d. Cruise Science--Encounter

All subsystem configurations are the same as those in encounter science--TV except for the following:

(1) CC and S is not required after t_{24} (this is the same as the calculation for cruise science--cruise).

(2) The tape recorder and planetary instrument scan are not required for this objective.

e. Engineering Data

All subsystems are as in cruise science--cruise except for the encoder subsystem. A complete numerical analysis of the data encoder has not been made by PRC. As the block diagrams (Exhibit 3* to 11*) indicate, there are many redundant paths involving the commutated low and medium rate decks. Since the scope of this contract rules out any such analysis, the reliability of the encoder subsystem includes only the series circuits, miscellaneous logic, A - D converter units, and the independent input channels of decks 100 and 110. The omitted portions would enter the calculations as a multiplier to the reliability considered here. Therefore, the probabilities developed should be interpreted as optimistic. The units used are:

Units	Time Required
Exhibit 3*	
2029, 2053, 2054, 2055, 2056, 2057, 2058, 2025, 2144	$t_0 - t_{25}$
Exhibit 4*	
2032, 2060, ..., 2066, 2026, 2145	$t_0 - t_{25}$
Exhibit 13*	
2015, 2013, 2012-1, 2003-3, 2041	$t_0 - t_{25}$
Exhibit 14*	
2023, 2020, 2019, 2018, 2017	$t_0 - t_{25}$
Exhibit 15*	
All units except 2006, 2004-2, 2003-2	$t_0 - t_{25}$

f. All Objectives

The probability computed is that all five objectives will be successfully met under the constraints of the Planned Sequence. Each subsystem enters the calculation with the probability associated with the longest time it is required among the five objectives, with one exception. The encoder system configuration must be a composite of two objectives, engineering and encounter science--TV. This configuration is:

Units	Time Required
Exhibit 15*	
Series circuits less 2006, 2004-2, 2003-2	$t_0 - t_{29}$
Exhibit 3*, 4*, 13*, 14* as in engineering objective	$t_0 - t_{25}$

4. Results

The probabilities developed as the result of subsection 3 are tabulated in Exhibit 4. The numbers shown in parentheses are the probabilities with the three operational probabilities omitted. The times shown in the table are, in general, the last time that subsystem is needed. Those instances where the beginning of the time required is not t_0, the beginning and end of the intervals are shown. It will be recalled from PRC's earlier work that units are considered (1) to be operating during an interval of time and a failure may occur, (2) energized but not needed until t_k, (3) not energized and not needed until t_k. In the second of these, once a unit becomes necessary, it is considered to have been operating since the first time it was energized. In the third case, operating time starts at t_k.

In interpreting Exhibit 4, careful attention should be given to the operating time. Some subsystems seem to have higher reliabilities than others; the difference may be in the length of required time. Examination of Exhibit 4 shows three systems with low probabilities: the star acquisition and tracking, the CC and S, and the encoder. As it turns out, these are the only subsystems for which alternative action may be taken in the event of a failure and the five objectives still be met. These three failure modes will be assessed in the following subsections.

D. Alternate Sequence: Inertial Roll Control

1. Problem

This alternate sequence results from a mode of operation possible in the event a failure occurs in the star tracker. Under this condition, the spacecraft is allowed to roll during the cruise period, and near encounter, attitude control in the roll position is maintained by on-board equipment and by radio command.

2. Assumptions

In addition to the assumptions discussed in subsection B above, two more are made. First, it is assumed that a failure will occur in the star tracker at some time t_a after midcourse maneuver. If it occurs after t_{25}, the inertial roll control equipment must remain operable from the entire 263 hours. Second, it is assumed that should a failure occur prior to t_{25}, the inertial roll control equipment would be tested for some length of time, but the greater portion of this 5900 hours the spacecraft is allowed to drift in the roll position. To approximate this condition, an arbitrary 26 hours of operation of the inertial roll control equipment is selected for the calculations below.

3. Calculations

Exhibit 5 shows the reliability block diagram for this alternate sequence. Four subsystem configurations are affected by the conditions of this sequence; all others remain as shown in Exhibit 3, the Planned Sequence. The attitude control star acquisition and tracking subsystem now is in a redundant path with the inertial roll control path shown in Exhibit 36*. This path requires two ground commands, DC-18, and DC-21, which in turn require the radio receiver and command series units to remain operable for the remainder of the flight (t_8-t_{29}). The power system is affected, since booster regulator number 2 must supply the maneuver loads of units 509, 510, 511, and 513.

Two of the secondary objectives in this alternate sequence may not be met under the inertial roll control mode of operation. That is, transmission of cruise science--cruise data and engineering data may be af-

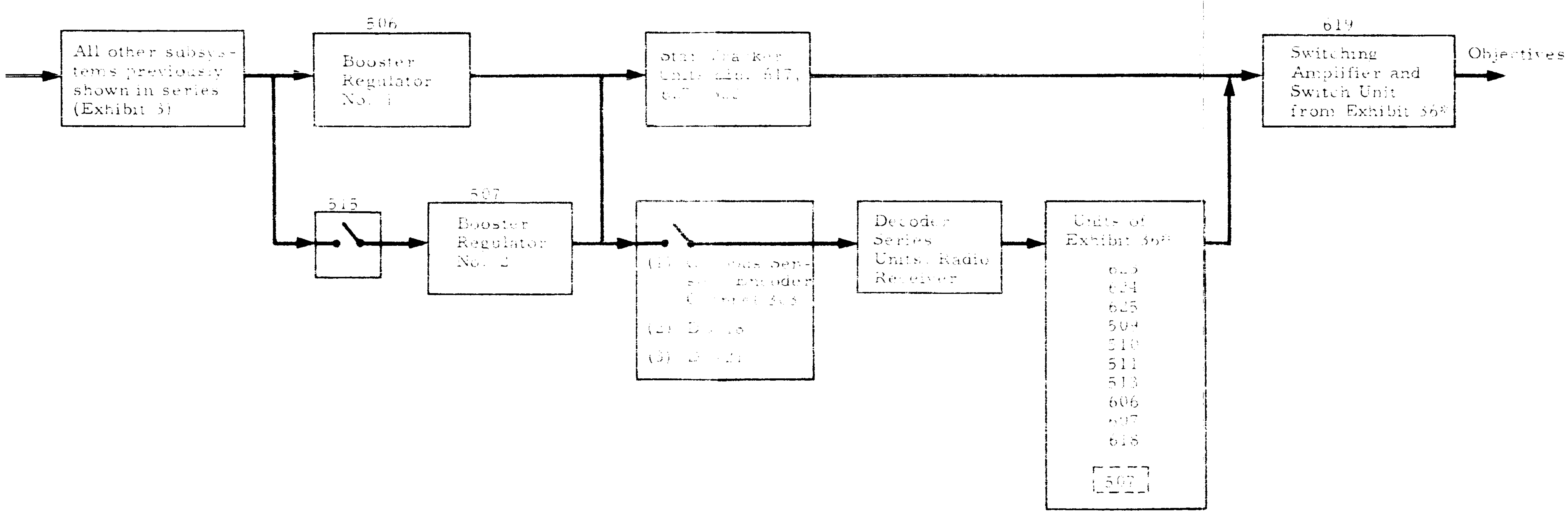


EXHIBIT 5 - SUBSYSTEMS FOR ALTERNATE SEQUENCE E: STAR TRACKER FAILED AND USE OF INERTIAL ROLL CONTROL

affected by the long free-roll period. The probabilities have been computed for these two objectives as though no degradation occurs.

The units required in four subsystems and their operating times are outlined below for each of the five objectives. All other subsystem configurations are the same for the particular objectives described in subsection C. 3 above.

a. Encounter Science--TV

(1) Star acquisition and tracking. This subsystem is required as in subsection C. 3. a through the acquisition after maneuver (t_{10}).

(2) Power through cruise and encounter. The redundant booster regulators are closely allied with the alternate configuration of inertial roll control and are removed as part of the power subsystem and included in (3) below. The remaining units are as the power subsystem of C. 3. a.

(3) Receiver, decoder series, inertial roll path, DC-18, DC-21. After t_{10} and before t_{25}, the units of the inertial roll control path shown in Exhibit 5 must be operable for 26 hours; after t_{25}, for 263 hours. The radio-command units and the command units for DC-18 and DC-21 must be available from t_{10} to t_{29}. A signal is required from the data encoder to indicate that Canopus has been lost; telemetry channel 303 is included for this purpose. This channel is considered the switch in the standby redundant path shown in Exhibit 5. A further complication is that when the inertial roll control path is used, booster regulator number 2 must be operable. This standby path is also shown in Exhibit 5. For calculation purposes, units 506, 507, and 515 from the power supply are included in this combination of subsystems.

It should be pointed out that in the calculations of the probabilities, the fact was considered that booster regulator number 1 may fail at any time t_b, $t_{10} \le t_b \le t_{29}$. Also, t_b may occur either before or after t_a, the time of star tracker failure. One simplifying assumption was made, however. The calculations are correct if the star tracker fails any time up to t_{25}-26 hours. For failures after this time, the calculations would include overlapping time. Since the total interval subjected to star tracker

failure is 6,169 hours, the additional calculations were considered of second order effect and were ignored.

The units needed and their operating times are:

Units	Time Required
Exhibit 36*	
616, 617, 627, 622	$t_{10} - t_{29}$
Exhibit 39*	
807, 808, 809, 836, 810	$t_{10} - t_{29}$
Exhibit 16*	
3079, 3000, 3001-1, 3002 3003	$t_{10} - t_{29}$
Exhibit 36*	
623, 624, 625, 510, 511, 513,	t = 26 hours; $t_{25} - t_{29}$
509, 606, 607, 618, 507 if required	t = 26 hours; $t_{25} - t_{29}$
619	$t_{10} - t_{29}$
Power Units	
506, 507, 515 redundancy	$t_{10} - t_{29}$
Exhibit 3*	
2051, 2025-1, -2, 2144	$t_{10} - t_{29}$
Exhibit 4*	
2021, 2068, 2027-1, -2, -3	$t_{10} - t_{29}$
2025, 2026 redundancy[1]	$t_{10} - t_{29}$
Exhibit 6*	
2093	$t_{10} - t_{29}$
2030-1, -2, -3, -4	$t_{10} - t_{29}$
2027-2028 redundancy[1]	$t_{10} - t_{29}$
Exhibit 14*	
2013, 2020, 2014, 2018, 2017	$t_{10} - t_{29}$
Exhibit 19*[2]	
All units (DC-18)	$t_{10} - t_{29}$

[1] Portions of these sequences are also series units.

[2] Actual unit numbers for these commands are found in PRC R-322, 6 May 1963.

Units	Time Required
Exhibit 22*[1]	
3011, 3014, 3015, 3017, 3041*, 3072-2 (additional units for DC-21)	$t_{10} - t_{29}$

b. Encounter Science--UV

All subsystems are the same as for encounter science--TV, except that the tape recorder is not needed.

c. Cruise Science--Cruise

The inertial roll control sequence is considered here only to the end of the cruise period. The operating time for the hardware associated with the redundant star tracker path is 26 hours for the gyros and associated equipment and 5,950 hours for the continuously operating equipment, instead of 289 and 6,169 as in encounter. The power subsystem is computed as in subsection C.3.c without the redundant booster regulators and for the cruise period only. The remaining subsystems are the same as in D.3.a.

d. Encounter Science--Encounter

Encounter must be made; therefore, the subsystems required for this objective are the same as in D.3.a. However, planetary instrument scan and the tape recorder are not needed.

e. Engineering

The four subsystems affected by this alternate sequence are computed as in cruise science--cruise for this sequence. All other subsystems are the same as in D.3.a.

f. All Objectives

Subsystems are the same as in D.3.a except for the four discussed above. The four for this objective are the same as encounter science--TV for this sequence.

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[1] Actual unit numbers for these commands are found in PRC R-322, 6 May 1963.

4. Results

Exhibit 6 tabulates the probabilities of achieving each objective under Alternate Sequence: Inertial Roll Control. As is to be expected, the numbers are higher than for the Planned Sequence. The increased reliability achieved from the inertial roll control path redundancy is not evident from Exhibit 6, however. The last row includes unit 619 which must remain operable in either case. Excluding this for the primary encounter objectives, the reliability of the redundant path is about 0.86, comparing to 0.79 with no redundancy.

In these numbers, as well as in the alternate sequences to follow, it should be remembered that the radio receiver and command series are a part of the redundant path. The probability that these two groups will survive the interval after t_{10} (maneuver) is 0.39. This number greatly affects the probability of the secondary path and this prevents the redundant path from increasing very much over the nominal path. The units involved are all series units and must operate over a long period of time (6,169 hours). Consideration of the fact that the receiver may operate sufficiently with a loss of gain of 15 db has not been included in the calculations. No way of accounting for this could be defined. However, the total possible increase in the redundant path can be seen by assigning the receiver a reliability of 1.0 rather than its calculated probability of 0.69. The reliability of the redundant paths due to just the receiver-command series units would then increase from 0.39 to 0.56.

E. Alternate Sequence: PNG/ADC

1. Problem

This alternate sequence considers a failure in the PN generator and analog-to-digital converter in the data encoder. In this event, alternate equipment is available which requires the availability of the radio-command units.

2. Assumptions

A minor assumption is made here for simplification of calculation; all other assumptions of subsection B apply. Two units involved in the redundant path of this sequence themselves have internal

EXHIBIT 6 - PROBABILITIES OF ACHIEVING OBJECTIVES--ALTERNATE SEQUENCE: STAR TRACKER FAILED AND USE OF INERTIAL ROLL CONTROL

	Objectives											
	Encounter Science--T.V.		Encounter Science--U.V.		Cruise Science--Cruise		Cruise Science--Encounter		Engineering Data		All Objectives	
Subsystem	Time	Reliability	Time	Reliability	Time	Reliability	Time	Reliability	Time	Reliability	Time	Reliability
Attitude Control Solar Vanes (P, Y, R jets)	$t_9 + 333$	0.9996	$t_9 - 333$	0.9996	$t_9 + 333$	0.9996	$t_9 + 333$	0.9996	$t_9 + 333$	0.9996	$t_9 + 333$	0.9996
Attitude Control Sun Acquisition and Tracking	t_9	0.998	t_9	0.998	t_9	0.998	t_9	0.998	t_9	0.998	t_9	0.998
Attitude Control Star Acquisition and Tracking	t_{10}	0.898 (0.998)	t_{10}	0.898 (0.998)	t_{10}	0.898 (0.998)	t_{10}	0.898 (0.998)	t_{10}	0.898 (0.998)	t_{10}	0.898 (0.998)
Roll Jets (after t_9 + 333 hours)	t_{29}	0.999	t_{29}	0.999	t_{29}	0.999	t_{29}	0.999	t_{29}	0.999	t_{29}	0.999
Central Computer and Sequencer	t_{29}	0.631	t_{29}	0.631	t_{24}	0.691	t_{29}	0.631	t_{24}	0.691	t_{29}	0.631
Power Through Midcourse	t_{10}	0.997	t_{10}	0.997	t_{10}	0.997	t_{10}	0.997	t_{10}	0.997	t_{10}	0.997
Power Encounter and Cruise	$t_{10}-t_{29}$	0.859 (0.877)	$t_{10}-t_{29}$	0.859 (0.877)	--	--	$t_{10}-t_{29}$	0.859 (0.877)	--	--	$t_{10}-t_{29}$	0.859 (0.877)
Power Cruise Only	--	--	--	--	$t_{10}-t_{25}$	0.972	--	--	$t_{10}-t_{25}$	0.972	--	--
Radio Receiver	t_8	0.997	t_8	0.997	t_8	0.997	t_8	0.997	t_8	0.997	t_8	0.997
Decoder	t_8	0.995	t_8	0.995	t_8	0.995	t_8	0.995	t_8	0.995	t_8	0.995
Encoder	t_{29}	0.482	t_{29}	0.482	t_{25}	0.508	t_{29}	0.482	t_{25}	0.259	t_{29}	0.253
Transmitter	t_{29}	0.945	t_{29}	0.945	t_{25}	0.948	t_{29}	0.945	t_{25}	0.948	t_{29}	0.945
Planetary Instrument Scan	t_E	0.969	t_E	0.969	--	--	--	--	--	--	t_E	0.969
Propulsion	t_8	0.970 (0.992)	t_8	0.970 (0.992)	t_8	0.970 (0.992)	t_8	0.970 (0.992)	t_8	0.970 (0.992)	t_8	0.970 (0.992)
Tape Recorder	t_{29}	0.966	--	--	--	--	--	--	--	--	t_{29}	0.966
Receiver, Decoder Series, Inertial Roll Path, DC-18, DC-21	$t_{10}-t_{29}$	0.806	$t_{10}-t_{29}$	0.806	$t_{10}-t_{25}$	0.922	$t_{10}-t_{29}$	0.806	$t_{10}-t_{25}$	0.922	$t_{10}-t_{29}$	0.806
Totals		0.160 (0.186)		0.166 (0.192)		0.256 (0.291)		0.187 (0.217)		0.131 (0.148)		0.084 (0.098)

Note: Numbers in parentheses eliminate the three operational probabilities.

redundancies.[1] The failure rate for units 2005 and 2006 is chosen as that rate which includes the redundancies throughout the flight even though the failure may occur at any time during the flight. The failure rate of the series portion alone of these two units is 9×10^{-6}. The assumption considers these units as series units only with a failure rate of 11×10^{-6}.

3. Calculations

Since only one subsystem failure is considered at a time, all subsystems other than the encoder have the same configuration as in the Planned Sequence. Exhibit 7 shows the reliability block diagram for this alternate sequence.

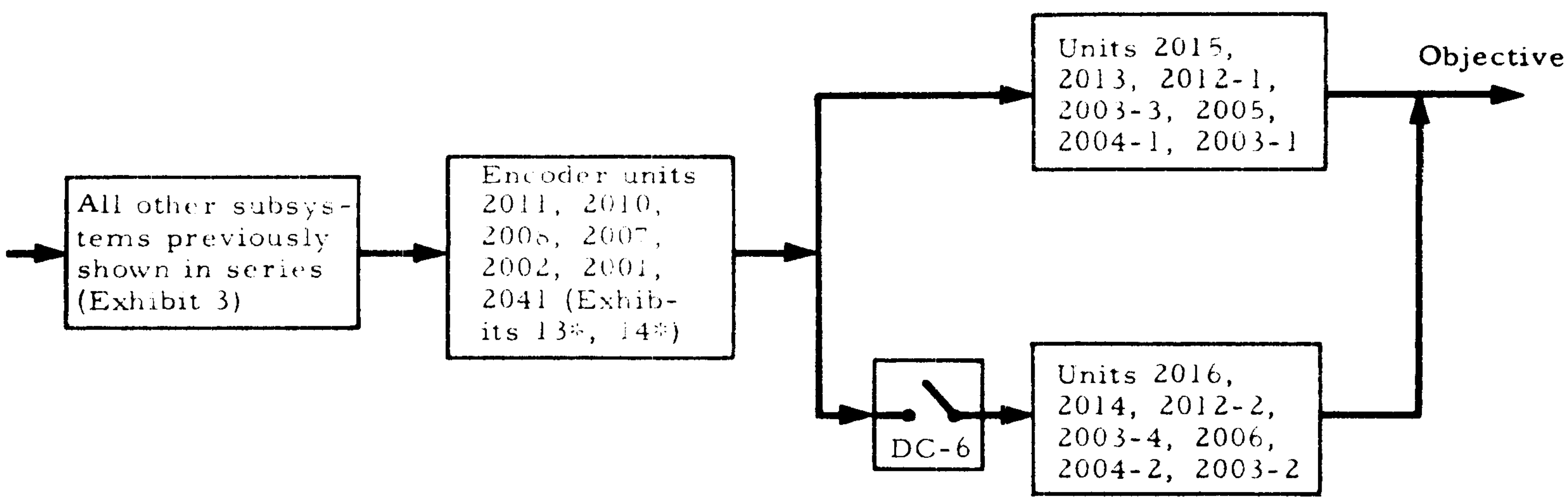
The receiver and command series units must be available as well as the units peculiar to DC-6. A failure is assumed to occur at some time t_c, $t_{10} \le t_c \le t_{29}$. DC-6 is the switch in the standby redundancy shown in Exhibit 7. The spare PN generator is not energized until needed, but the remaining units, 2004-2, and 2003-2, once needed appear in the equations as if they had been operating from t_0. The A-D converter is omitted from the calculation, since the probability of surviving its redundant configuration is high, 0.97. The complete standby redundant path for this sequence is more significantly influenced by the reliability of the receiver-command units.

The encoder units necessary for the calculations are outlined below. All other subsystems enter as in subsection C.3 for each of the objectives.

a. Encounter Science--TV

The encoder units through maneuver, t_{10}, are the same as in C.3.a; the operating time here is 44.5 hours. After this interval and throughout the flight the following units are used: the radio receiver, the command series, the data encoder series, and the encoder miscellaneous logic. The latter are needed for Canopus cone angle update sequences.

[1] PRC R-362, p. 96.



Note: Some objectives do not require A-D converter. Block diagram shows both PNG and ADC redundancy.

EXHIBIT 7 - SUBSYSTEMS FOR ALTERNATE SEQUENCE: PNG/ADC FAILED AND USE OF SPARE PNG/ADC

Units	Time Required
Exhibit 15*	
2011, 2010, 2008, 2007, 2002, 2001	$t_{10} - t_{29}$
2005, 2004-1, 2003-1, 2006, 2004-2, 2003-2 redundancy	$t_{10} - t_{29}$
Exhibit 17*[1]	
3005, 3006-1, 3007-1, 3008-1,	$t_{10} - t_{29}$
3010, 3011, 3013, 3016 3018, 3020, 3026*, 3051-2	$t_{10} - t_{29}$
Exhibit 14*	
2023, 2020, 2019, 2018 2017	$t_{10} - t_{29}$
Exhibit 16*	
3079, 3000, 3001-1, 3002, 3003	$t_{10} - t_{29}$
Exhibit 39*	
807, 808, 809, 836, 810	$t_{10} - t_{29}$

b. Encounter Science--UV

All subsystems are the same as for encounter science--UV except that, as before, the tape recorder is not needed.

c. Cruise Science--Cruise

The encoder units through t_{10} are as in C.3.c, where operating time now stops at t_{10}. After t_{10} the miscellaneous logic and the series circuits including the standby redundant path with the radio command is computed as in encounter science--TV; operating time stops at t_{25}, the end of the cruise period. In addition, the redundant sequences, 2025 and 2026 as shown in Exhibit 12*, are needed for the interval $t_{10} - t_{25}$.

[1] Unit numbers are found in PRC R-322, 6 May 1963.

d. Cruise Science--Encounter

The encoder units are configured the same as in encounter science--TV. Other subsystems are the same as in C. 3. d.

e. Engineering

The encoder units up to t_{10} are the same as in C. 3. e, with 44.5 hours of operation. The series encoder units are the same as in cruise science--cruise; operating time is also the same, $t_{10} - t_{25}$. The remaining encoder units are as in C. 3. e from $t_{10} - t_{25}$.

f. All Objectives

The encoder units for this objective are the same as in C. 3. f except that the series circuits are replaced by the series circuits with the standby redundant path calculated as in encounter science--TV above.

4. Results

Exhibit 8 gives the probabilities for meeting each of the objectives under this alternate sequence. As in each of the alternate sequences, the requirement for the receiver-command series units significantly affects the alternate path. In this sequence a relatively high probability of survival throughout the flight of the encoder series circuit with the primary PNG, 0.88, is not appreciably increased by the standby redundancy. The probability of the series circuits is increased to 0.92. The series units not in the redundant path have a probability of 0.60 of surviving the flight.

F. Alternate Sequence: CC and S and Radio Commands

1. Problem

After midcourse maneuver, all nine master timer signals have radio command backup. If the CC and S fails at any time, then the radio command units must be available to perform these nine tasks.

2. Assumptions

The first assumption is that the two systems are in a simple redundant relationship, with the receiver and command series units

EXHIBIT 8 - PROBABILITIES OF ACHIEVING OBJECTIVES--ALTERNATE SEQUENCE: PNG/ADC FAILED AND USE OF SPARE PNG/ADC

Subsystem	Objectives: Encounter Science--T.V. Time	Encounter Science--T.V. Reliability	Encounter Science--U.V. Time	Encounter Science--U.V. Reliability	Cruise Science--Cruise Time	Cruise Science--Cruise Reliability	Cruise Science--Encounter Time	Cruise Science--Encounter Reliability	Engineering Data Time	Engineering Data Reliability	All Objectives Time	All Objectives Reliability
Attitude Control Solar Vanes (P, Y, R jets)	$t_9 + 333$	0.9996	$t_9 + 333$	0.9996	$t_9 + 333$	0.9996	$t_9 + 333$	0.9996	$t_9 + 333$	0.9996	$t_9 + 333$	0.9996
Attitude Control Sun Acquisition and Tracking	t_9	0.998	t_9	0.998	t_9	0.998	t_9	0.998	t_9	0.998	t_9	0.998
Attitude Control Star Acquisition and Tracking	t_{29}	0.667 (0.741)	t_{29}	0.667 (0.741)	t_{25}	0.697 (0.774)	t_{29}	0.667 (0.741)	t_{25}	0.697 (0.774)	t_{29}	0.667 (0.741)
Roll Jets (after t_9 + 333 hours)	t_{29}	0.999	t_{29}	0.999	t_{29}	0.999	t_{29}	0.999	t_{29}	0.999	t_{29}	0.999
Central Computer and Sequencer	t_{29}	0.631	t_{29}	0.631	t_{24}	0.691	t_{29}	0.631	t_{24}	0.691	t_{29}	0.631
Power Through Midcourse	t_{10}	0.997	t_{10}	0.997	t_{10}	0.995	t_{10}	0.997	t_{10}	0.997	t_{10}	0.997
Power Encounter and Cruise	$t_{10}-t_{29}$	0.852 (0.870)	$t_{10}-t_{29}$	0.852 (0.870)	--	--	$t_{10}-t_{29}$	0.852 (0.870)	--	--	$t_{10}-t_{29}$	0.852 (0.870)
Power Cruise Only	--	--	--	--	$t_{10}-t_{25}$	0.964	--	--	$t_{10}-t_{25}$	0.964	--	--
Radio Receiver	t_8	0.997	t_8	0.997	t_8	0.997	t_8	0.997	t_8	0.997	t_8	0.997
Decoder	t_8	0.995	t_8	0.995	t_8	0.995	t_8	0.995	t_8	0.995	t_8	0.995
Encoder	t_{10}	0.995	t_{10}	0.995	t_{10}	0.995	t_{10}	0.995	t_{10}	0.994	t_{10}	0.995
Transmitter	t_{29}	0.945	t_{29}	0.945	t_{25}	0.948	t_{29}	0.945	t_{25}	0.948	t_{29}	0.945
Planetary Instrument Scan	t_E	0.969	t_E	0.969	--	--	--	--	--	--	t_E	0.969
Propulsion	t_8	0.970 (0.992)	t_8	0.970 (0.992)	t_8	0.970 (0.992)	t_8	0.970 (0.992)	t_8	0.970 (0.992)	t_8	0.970 (0.992)
Tape Recorder	t_{29}	0.966	--	--	--	--	--	--	--	--	t_{29}	0.966
Receiver, Decoder Series, DC-6, Encoder	$t_{10}-t_{29}$	0.513	$t_{10}-t_{29}$	0.513	$t_{10}-t_{25}$	0.534	$t_{10}-t_{29}$	0.513	$t_{10}-t_{25}$	0.274	$t_{10}-t_{29}$	0.269
Totals		0.155 (0.179)		0.160 (0.185)		0.224 (0.254)		0.181 (0.210)		0.115 (0.130)		0.084 (0.097)

Note: Numbers in parentheses eliminate the three operational probabilities.

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required throughout the flight and the particular hardware associated with the necessary commands being operable up to the time they are required (and forming the secondary path). A second assumption is made concerning specific failure times for the CC and S; the command system then becomes the only path after that time.

All other assumptions of III. B apply.

3. Calculations

Exhibit 9 is the reliability diagram for the simple redundant relationship. Since only failure of the CC and S is considered in this alternate sequence, all but one of the other subsystems are unaffected and appear for each objective as in III. C. 3. The encoder will include telemetry channel 303 as a signal that the master timer update commands are not given. The configurations for the subsystems in cases where specific times of CC and S failure are considered are similar, except that commands become series units if their need occurs after the time of CC and S failure.

The subsystem units are required for each objective as they appear in that objective in III. C. 3, except that (1) there are time changes in the CC and S, (2) receiver-command series units are required after t_{10}, (3) certain individual command units are required for the master-timer commands after t_{10}. These changes are outlined below for each objective.

a. Encounter Science--TV

The CC and S units are configured as in III. C. 3. a. The six operating times are intervals ending with t_{29}, t_E, t_{24}, t_{20}, t_{17}, t_{10}. The CC and S must operate through t_{10} in order that the maneuver be successful, a basic assumption in the study. The receiver-command series units previously defined are not required in these intervals, but must operate in a series manner after each interval through t_{29}. The individual command units enter into the calculations in a similar manner, dependent on whether or not the time of their execution occurs within the interval of consideration.

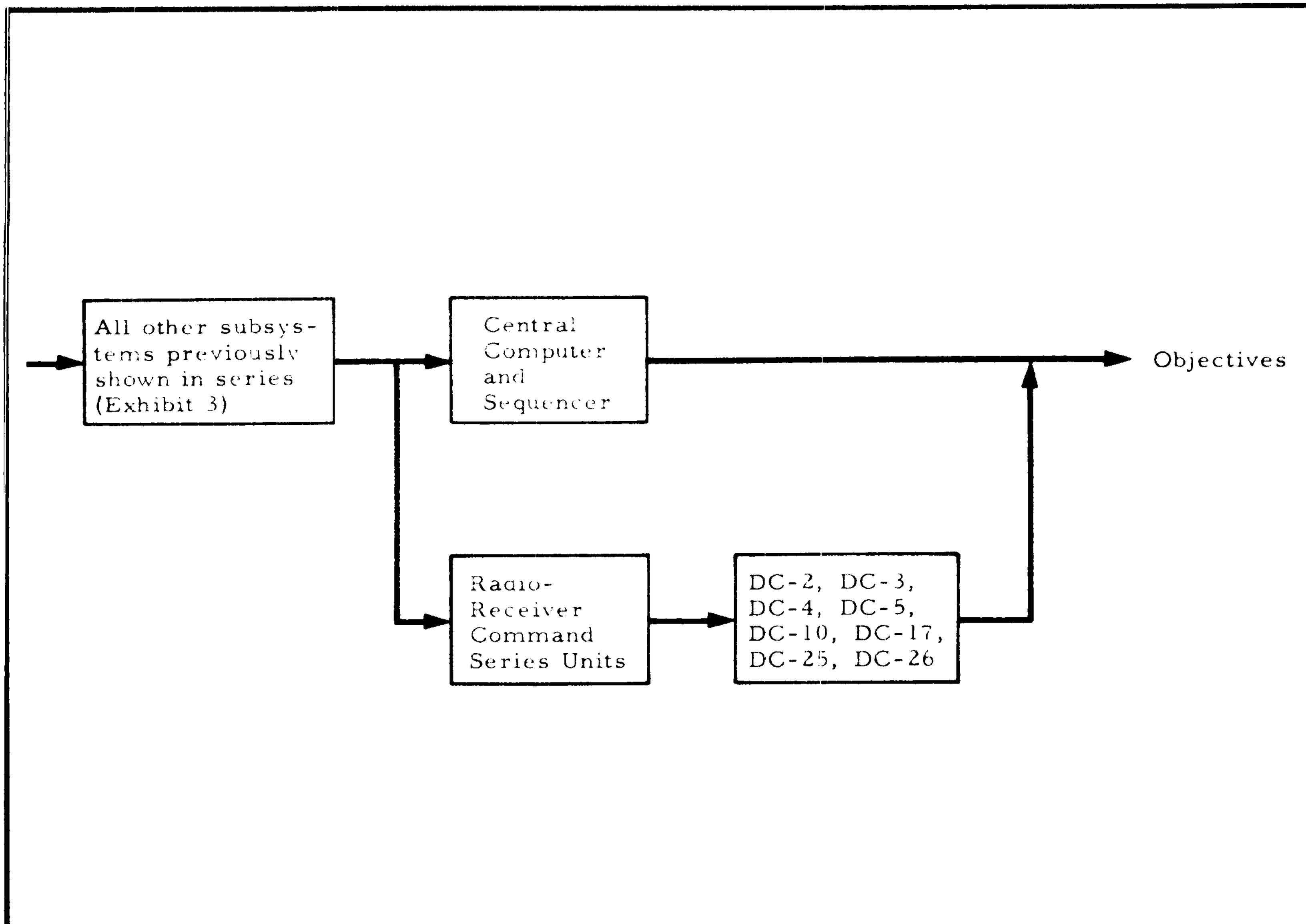

EXHIBIT 9 - SUBSYSTEMS FOR ALTERNATE SEQUENCE: CC AND S FAILED AND USE OF RADIO COMMANDS

The individual command units required are as follows.

Units[1]	Time Required
Exhibit 18*	
DC-2	t_E
Exhibit 19*	
DC-3	t_E
Exhibit 19*	
DC-4	t_{28}
Exhibit 19*	
DC-5	t_{17}
Exhibit 19*	
DC-10	t_{20}
Exhibit 19*	
DC-17	t_{24}
Exhibit 21*	
DC-25	t_{26}
Exhibit 19*	
DC-26	t_{27}

It should be noted that in the calculations, many of these commands have common units, and the operating times should not overlap for a given interval.

The encoder units for this objective are the same as in III. C. 3. a, with the addition that in all CC and S specific failure instances, telemetry channel 303 (previously defined) and the A-D converter units of Exhibit 13* are required through t_{24}.

b. Encounter Science--UV

All subsystem calculations are the same as in encounter science--TV, except that the tape recorder is not required.

[1] Command unit numbers may be found in other PRC R-362 or PRC R-322.

c. Cruise Science--Cruise

Unit configurations are the same as discussed for encounter science--TV, except for the encoder. The encoder configuration of III. C. 3. c is used with the addition of telemetry channel 303 and the A-D converter. All operating times after t_{25} are omitted.

d. Cruise Science--Encounter

All subsystems other than the CC and S and radio-command after t_{10} are as in III. C. 3. d. After t_{10}, the CC and S and radio command enter as in encounter science--TV for this sequence.

e. Engineering

The redundant paths considered in this sequence enter for the same operating time (up to t_{25}) and in the same configuration as in cruise science--cruise. All other subsystems are as in III. C. 3. e, except to the encoder system as computed there is added the telemetry channel 303 up to t_{24}.

f. All Objectives

The redundant subsystem calculations are the same as for encounter science--TV. All other subsystems are the same as in III. C. 3. f, with the encoder configuration being modified by the addition of the telemetry channel 303 to t_{24}.

4. Results

Exhibit 10 gives the probabilities of meeting the objectives when the CC and S and radio command subsystems are considered redundant paths for the entire flight. Viewed in this manner, the increased reliability of achieving the objectives is the result of increasing the primary path (CC and S above) from 0.63 to the redundant path (CC and S and radio commands) of 0.74. As before, a further increase is largely prohibited by the low reliability of the radio command subsystem (0.39 at t_{29}).

Exhibit 11 shows that if the CC and S fails at either t_{10} or t_{17}, the probability of achieving the objectives by the radio command is low,

EXHIBIT 10 - PROBABILITIES OF ACHIEVING OBJECTIVES--ALTERNATE SEQUENCE: CC AND S FAILED AND USE OF RADIO COMMANDS

	Objectives											
	Encounter Science--T.V.		Encounter Science--U.V.		Cruise Science--Cruise		Cruise Science--Encounter		Engineering Data		All Objectives	
Subsystem	Time	Reliability	Time	Reliability	Time	Reliability	Time	Reliability	Time	Reliability	Time	Reliability
Attitude Control Solar Vanes (P, Y, R jets)	$t_9 + 333$	0.9996	$t_9 + 333$	0.9996	$t_9 - 333$	0.9996	$t_9 + 333$	0.9996	$t_9 + 333$	0.9996	$t_9 + 333$	0.9996
Attitude Control Sun Acquisition and Tracking	t_9	0.998	t_9	0.998	t_9	0.998	t_9	0.998	t_9	0.998	t_9	0.998
Attitude Control Star Acquisition and Tracking	t_{29}	0.667 (0.741)	t_{29}	0.667 (0.741)	t_{25}	0.697 (0.774)	t_{29}	0.667 (0.741)	t_{25}	0.697 (0.774)	t_{29}	0.667 (0.741)
Roll Jets (after t_9 + 333 hours)	t_{29}	0.999	t_{29}	0.999	t_{25}	0.999	t_{29}	0.999	t_{29}	0.999	t_{29}	0.999
Central Computer and Sequencer	t_{10}	0.992	t_{10}	0.992	t_{10}	0.992	t_{10}	0.992	t_{10}	0.992	t_{10}	0.992
Power Through Midcourse	t_{10}	0.997	t_{10}	0.997	t_{10}	0.997	t_{10}	0.997	t_{10}	0.997	t_{10}	0.997
Power Encounter and Cruise	$t_{10}-t_{29}$	0.852 (0.870)	$t_{10}-t_{29}$	0.852 (0.870)	--	--	$t_{10}-t_{29}$	0.852 (0.870)	--	--	$t_{10}-t_{29}$	0.852 (0.870)
Power Cruise Only	--	--	--	--	$t_{10}-t_{25}$	0.964	--	--	$t_{10}-t_{25}$	0.964	--	--
Radio Receiver	t_8	0.997	t_8	0.997	t_8	0.997	t_8	0.997	t_8	0.997	t_8	0.997
Decoder	t_8	0.995	t_8	0.995	t_8	0.995	t_8	0.995	t_8	0.995	t_8	0.995
Encoder	t_{29}	0.482	t_{29}	0.482	t_{25}	0.508	t_{29}	0.482	t_{25}	0.259	t_{29}	0.253
Transmitter	t_{29}	0.945	t_{29}	0.945	t_{25}	0.948	t_{29}	0.945	t_{25}	0.946	t_{29}	0.945
Planetary Instrument Scan	t_E	0.969	t_E	0.969	--	--	--	--	--	--	t_E	0.969
Propulsion	t_8	0.970 (0.992)	t_8	0.970 (0.992)	t_8	0.970 (0.992)	t_8	0.970 (0.992)	t_8	0.970 (0.992)	t_8	0.970 (0.992)
Tape Recorder	t_{29}	0.966	--	--	--	--	--	--	--	--	t_{29}	0.966
Central Computer and Sequencer and Radio Command	$t_{10}-t_{29}$	0.743	$t_{10}-t_{29}$	0.743	$t_{10}-t_{29}$	0.743	$t_{10}-t_{29}$	0.743	$t_{10}-t_{29}$	0.743	$t_{10}-t_{29}$	0.743
Totals		0.176 (0.204)		0.177 (0.276)		0.228 (0.348)		0.182 (0.212)		0.117 (0.178)		0.091 (0.105)

Note: Numbers in parentheses eliminate the three operational probabilities.

EXHIBIT 11 - PROBABILITIES OF ACHIEVING OBJECTIVES IF CONTROL IS SWITCHED TO RADIO COMMANDS AT TIME t_{10} OR t_{17}

	Objectives											
	Encounter Science-- T.V.		Encounter Science-- U.V.		Cruise Science-- Cruise		Cruise Science-- Encounter		Engineering Data		All Objectives	
Subsystem	Time	Reliability	Time	Reliability	Time	Reliability	Time	Reliability	Time	Reliability	Time	Reliability
Attitude Control Solar Vanes (P, Y, R jets)	$t_9 + 333$	0.9996	$t_9 + 333$	0.9996	$t_9 + 333$	0.9996	$t_9 + 333$	0.9996	$t_9 + 333$	0.9996	$t_9 + 333$	0.9996
Attitude Control Sun Acquisition and Tracking	t_9	0.998	t_9	0.998	t_9	0.998	t_9	0.998	t_9	0.998	t_9	0.998
Attitude Control Star Acquisition and Tracking	t_{29}	0.667 (0.741)	t_{29}	0.667 (0.741)	t_{25}	0.697 (0.774)	t_{29}	0.667 (0.741)	t_{25}	0.697 (0.774)	t_{29}	0.667 (0.741)
Roll Jets (after t_9 + 333 hours)	t_{29}	0.999	t_{29}	0.999	t_{29}	0.999	t_{29}	0.999	t_{29}	0.999	t_{29}	0.999
Central Computer and Sequencer	t_{10}	0.992	t_{10}	0.992	t_{10}	0.992	t_{10}	0.992	t_{10}	0.992	t_{10}	0.992
Power Through Midcourse	t_{10}	0.997	t_{10}	0.997	t_{10}	0.997	t_{10}	0.997	t_{10}	0.997	t_{10}	0.997
Power Encounter and Cruise	$t_{10}-t_{29}$	0.852 (0.870)	$t_{10}-t_{29}$	0.852 (0.870)	--	--	$t_{10}-t_{29}$	0.852 (0.870)	--	--	$t_{10}-t_{29}$	0.852 (0.870
Power Cruise Only	--	--	--	--	$t_{10}-t_{25}$	0.964	--	--	$t_{10}-t_{25}$	0.964	--	--
Radio Receiver	t_8	0.997	t_8	0.997	t_8	0.997	t_8	0.997	t_8	0.997	t_8	0.997
Decoder	t_8	0.995	t_8	0.995	t_8	0.995	t_8	0.995	t_8	0.995	t_8	0.995
Encoder	t_{29}	0.377	t_{29}	0.377	t_{25}	0.397	t_{29}	0.377	t_{25}	0.218	t_{29}	0.213
Transmitter	t_{29}	0.945	t_{29}	0.945	t_{25}	0.948	t_{29}	0.945	t_{25}	0.948	t_{29}	0.945
Planetary Instrument Scan	t_E	0.969	t_E	0.969	--	--	--	--	--	--	t_E	0.969
Propulsion	t_8	0.970 (0.992)	t_8	0.970 (0.992)	t_8	0.970 (0.992)	t_8	0.970 (0.992)	t_8	0.970 (0.992)	t_8	0.970 (0.992)
Tape Recorder	t_{29}	0.966	--	--	--	--	--	--	--	--	t_{29}	0.966
Receiver, Decoder, Commands as Needed	t_8-t_{29}	0.300	t_8-t_{29}	0.300	t_8-t_{29}	0.300	t_8-t_{29}	0.300	t_8-t_{29}	0.300	t_8-t_{29}	0.300
Totals		0.054 (0.060)		0.056 (0.065)		0.072 (0.081)		0.058 (0.067)		0.040 (0.045)		0.030 (0.035)

Note: Numbers shown are probabilities of achieving objectives with the CC&S failing at t_{10}, t_{17}. The probability of the CC&S failing @ t_{10} = 0.008; @ t_{17} = 0.108. Numbers in parentheses eliminate the three operational probabilities.

for the reason just mentioned. The individual command units that are different among these times do not change the objective probabilities. It is important to note that the probability of having to depend on the radio command subsystem is the probability of CC and S failure at the various times; at t_{10}, 0.008; at t_{17}, 0.11. A similar calculation at t_{20} is given in the summary table (see Exhibit 16); individual subsystem numbers are not given in this report.

Exhibit 12 gives the objective probabilities if the CC and S fails at t_{24}. The probability that it does is 0.33. Exhibit 13 is for CC and S failure at t_e, with a probability of 0.36.

The probabilities in Exhibits 11, 12, and 13 are not conditional probabilities; they are the reliability of the sequence which requires the CC and S up to a specific time and radio commands to be available after that time.

G. Summary

1. All Alternatives

In all of the calculations so far, the alternate sequences were developed by considering the possible action in the event of a failure in one subsystem at a time. It is evident that each alternate sequence depends mainly on the availability of the receiver and command series units. Increases in the reliability of subsystems can be investigated by the one-at-a-time procedure, and the magnitude of the numbers makes consideration of combination of failures impractical. However, the subsystem probabilities of achieving the objectives in a sequence in which all alternatives are available are presented in Exhibit 14.

The calculations are made on the basis that if the radio command units fail, then the only way of meeting the objectives is by the Planned Sequence; if they are up, then the objectives are met either by the Planned Sequence or the Alternate Sequences. The hardware configurations and operating times are a composite of those described in subsections III.C, III.D, III.E, and III.F.

2. Summary of Sequences

Exhibit 15 summarizes the probabilities of meeting each objective in each of the five sequences. The numbers in parentheses are

EXHIBIT 12 - PROBABILITIES OF ACHIEVING OBJECTIVES IF CONTROL IS SWITCHED TO RADIO COMMANDS AT TIME t_{24}

	Objectives											
	Encounter Science--T.V.		Encounter Science--U.V.		Cruise Science--Cruise		Cruise Science--Encounter		Engineering Data		All Objectives	
Subsystem	Time	Reliability	Time	Reliability	Time	Reliability	Time	Reliability	Time	Reliability	Time	Reliability
Attitude Control Solar Vanes (P, Y, R jets)	$t_9 + 333$	0.9996	$t_9 + 333$	0.9996	$t_{[illegible]}$	0.9996	$t_9 + 333$	0.9996	$t_9 + 333$	0.9996	$t_9 + 333$	0.9996
Attitude Control Sun Acquisition and Tracking	t_9	0.998	t_9	0.998	$t_{[illegible]}$	0.998	t_9	0.998	t_9	0.998	t_9	0.998
Attitude Control Star Acquisition and Tracking	t_{29}	0.667 (0.741)	t_{29}	0.667 (0.741)	$t_{[illegible]}$	0.697 (0.774)	t_{29}	0.667 (0.741)	t_{25}	0.697 (0.774)	t_{29}	0.667 (0.741)
Roll Jets (after t_9 - 333 hours)	t_{29}	0.999	t_{29}	0.999	$t_{[illegible]}$	0.999	t_{29}	0.999	t_{25}	0.999	t_{29}	0.999
Central Computer and Sequencer	t_{22}	0.738	t_{22}	0.738	$t_{[illegible]}$	0.738	t_{22}	0.738	t_{22}	0.738	t_{22}	0.738
Power Through Midcourse	t_{10}	0.997	t_{10}	0.997	$t_{[illegible]}$	0.997	t_{10}	0.997	t_{10}	0.997	t_{10}	0.997
Power Encounter and Cruise	$t_{10}-t_{29}$	0.852 (0.870)	$t_{10}-t_{29}$	0.852 (0.870)	--	--	$t_{10}-t_{29}$	0.852 (0.870)	--	--	$t_{10}-t_{29}$	0.852 (0.870)
Power Cruise Only	--	--	--	--	$t_{[illegible]}-t_{25}$	0.964	--	--	$t_{10}-t_{25}$	0.964	--	--
Radio Receiver	t_8	0.997	t_8	0.997	$t_{[illegible]}$	0.997	t_8	0.997	t_8	0.997	t_8	0.997
Decoder	t_8	0.995	t_8	0.995	$t_{[illegible]}$	0.995	t_8	0.995	t_8	0.995	t_8	0.995
Encoder	t_{29}	0.377	t_{29}	0.377	$t_{[illegible]}$	0.397	t_{29}	0.377	t_{25}	0.213	t_{29}	0.213
Transmitter	t_{29}	0.945	t_{29}	0.945	$t_{[illegible]}$	0.948	t_{29}	0.945	t_{25}	0.948	t_{29}	0.945
Planetary Instrument Scan	t_E	0.969	t_E	0.969	--	--	--	--	--	--	t_E	0.969
Propulsion	t_8	0.970 (0.992)	t_8	0.970 (0.992)	t_8	0.970 (0.992)	t_8	0.970 (0.992)	t_8	0.970 (0.992)	t_8	0.970 (0.992)
Tape Recorder	t_{29}	0.966	--	--	--	--	--	--	--	--	t_{29}	0.966
Receiver, Decoder, Commands as Needed	t_8-t_{29}	0.227	t_8-t_{29}	0.227	t_8-t_{29}	0.227	t_8-t_{29}	0.227	t_8-t_{27}	0.227	t_8-t_{29}	0.227
Totals		0.031 (0.035)		0.031 (0.036)		0.041 (0.046)		0.031 (0.038)		0.022 (0.025)		0.017 (0.020)

Note: Numbers shown are probabilities of achieving objectives with the CC & S failing at t_{24}. The probability of the CC&S failing @ t_{24} = 0.329.
Numbers in parentheses eliminate the three operational probabilities.

EXHIBIT 13 - PROBABILITIES OF ACHIEVING OBJECTIVES IF CONTROL IS SWITCHED TO RADIO COMMANDS AT TIME t_E

	Objectives											
	Encounter Science--F.V.		Encounter Science--U.V.		Science--Cruise		Cruise Science--Encounter		Engineering Data		All Objectives	
Subsystem	Time	Reliability	Time	Reliability	Time	Reliability	Time	Reliability	Time	Reliability	Time	Reliability
Attitude Control Solar Vanes (P, Y, R jets)	$t_0 + 333$	0.9996	$t_0 + 333$	0.9996	t_E	0.9996	$t_0 + 333$	0.9996	[illegible]	0.9996	$t_0 + 333$	0.9996
Attitude Control Sun Acquisition and Tracking	t_9	0.998	t_9	0.998	t_9	0.998	t_9	0.998	t_9	0.998	t_9	0.998
Attitude Control Star Acquisition and Tracking	t_{29}	0.667 (0.741)	t_{29}	0.667 (0.741)	t_{25}	0.697 (0.774)	t_{29}	0.667 (0.741)	t_{25}	0.697 (0.774)	t_{29}	0.667 (0.741)
Roll Jets (after t_0 + 333 hours)	t_{29}	0.999	t_{29}	0.999	t_{25}	0.999	t_{29}	0.999	t_{25}	0.999	t_{29}	0.999
Central Computer and Sequencer	t_{24}	0.671	t_{24}	0.671	t_{24}	0.671	t_{24}	0.671	t_{24}	0.671	t_{24}	0.671
Power Through Midcourse	t_{10}	0.997	t_{10}	0.997	t_{10}	0.997	t_{10}	0.997	t_{10}	0.997	t_{10}	0.997
Power Encounter and Cruise	$t_{10}-t_{29}$	0.852 (0.870)	$t_{10}-t_{29}$	0.852 (0.870)	--	--	$t_{10}-t_{29}$	0.852 (0.870)	--	--	$t_{10}-t_{29}$	0.852 (0.870)
Power Cruise Only	--	--	--	--	$t_{10}-t_{25}$	0.964	--	--	$t_{10}-t_{25}$	0.964	--	--
Radio Receiver	t_8	0.997	t_8	0.997	t_8	0.997	t_8	0.997	t_8	0.997	t_8	0.997
Decoder	t_8	0.995	t_8	0.995	t_8	0.995	t_8	0.995	t_8	0.995	t_8	0.995
Encoder	t_{29}	0.377	t_{29}	0.377	t_{25}	0.397	t_{29}	0.482	t_{25}	0.218	t_{29}	0.213
Transmitter	t_{29}	0.945	t_{29}	0.945	t_{25}	0.948	t_{29}	0.945	t_{25}	0.948	t_{29}	0.945
Planetary Instrument Scan	t_E	0.969	t_E	0.969	--	--	--	--	--	--	t_E	0.969
Propulsion	t_8	0.970 (0.992)	t_8	0.970 (0.992)	t_8	0.970 (0.992)	t_8	0.970 (0.992)	t_8	0.970 (0.992)	t_8	0.970 (0.992)
Tape Recorder	t_{29}	0.966	--	--	--	--	--	--	--	--	t_{29}	0.966
Receiver, Decoder, Commands as Needed	t_8-t_{29}	0.308	t_8-t_{29}	0.308	t_8-t_{29}	0.308	t_8-t_{29}	0.308	t_8-t_{29}	0.308	t_8-t_{29}	0.308
Totals		0.037 (0.043)		0.034 (0.040)		0.050 (0.057)		0.051 (0.060)		0.028 (0.031)		0.021 (0.024)

Note: Numbers shown are probabilities of achieving objectives with the CC & S failing at t_{26}. The probability of the CC&S failing @ t_{26} = 0.360. Numbers in parentheses eliminate the three operational probabilities.

EXHIBIT 14 - PROBABILITIES OF ACHIEVING OBJECTIVES--ALL ALTERNATE SEQUENCES

	Objectives											
	Encounter Science--T.V.		Encounter Science--U.V.		Cruise Science--Cruise		Cruise Science--Encounter		Engineering Data		All Objectives	
Subsystem	Time	Reliability	Time	Reliability	Time	Reliability	Time	Reliability	Time	Reliability	Time	Reliability
Attitude Control Solar Vanes (P, Y, R jets)	$t_9 + 333$	0.9996	$t_9 + 333$	0.9996	$t_9 + 333$	0.9996	$t_9 + 333$	0.9996	$t_9 + 333$	0.9996	$t_9 + 333$	0.9996
Attitude Control Sun Acquisition and Tracking	t_9	0.998	t_9	0.998	t_9	0.998	t_9	0.998	t_9	0.998	t_9	0.998
Attitude Control Star Acquisition and Tracking	t_{10}	0.898	t_{10}	0.898	t_{10}	0.898	t_{10}	0.898	t_{10}	0.898	t_{10}	0.898
Roll Jets (after t_9 + 333 hours)	t_{29}	0.999	t_{29}	0.999	t_{25}	0.999	t_{29}	0.999	t_{25}	0.999	t_{29}	0.999
Central Computer and Sequencer	t_{10}	0.992	t_{10}	0.992	t_{10}	0.992	t_{10}	0.992	t_{10}	0.992	t_{10}	0.992
Power Through Midcourse	t_{10}	0.997	t_{10}	0.997	t_{10}	0.997	t_{10}	0.997	t_{10}	0.997	t_{10}	0.997
Power Encounter and Cruise	$t_{10}-t_{29}$	0.859	$t_{10}-t_{29}$	0.859	--	--	$t_{10}-t_{29}$	0.859	--	--	$t_{10}-t_{29}$	0.859
Power Cruise Only	--	--	--	--	$t_{10}-t_{25}$	0.972	--	--	$t_{10}-t_{25}$	0.972	--	--
Radio Receiver	t_8	0.997	t_8	0.997	t_8	0.997	t_8	0.997	t_8	0.997	t_8	0.997
Decoder	t_8	0.995	t_8	0.995	t_8	0.995	t_8	0.995	t_8	0.995	t_8	0.995
Encoder	t_{29}	0.545	t_{29}	0.545	t_{25}	0.559	t_{29}	0.545	t_{25}	0.299	t_{29}	0.287
Transmitter	t_{29}	0.945	t_{29}	0.945	t_{25}	0.948	t_{29}	0.945	t_{25}	0.948	t_{29}	0.945
Planetary Instrument Scan	t_E	0.969	t_E	0.969	--	--	--	--	--	--	t_E	0.969
Propulsion	t_8	0.970	t_8	0.970	t_8	0.970	t_8	0.970	t_8	0.970	t_8	0.970
Tape Recorder	t_{29}	0.966	--	--	--	--	--	--	--	--	t_{29}	0.966
All Three Redundant Paths	$t_{10}-t_{29}$	0.519	$t_{10}-t_{29}$	0.519	$t_{10}-t_{25}$	0.588	$t_{10}-t_{29}$	0.519	t_{25}	0.588	$t_{10}-t_{29}$	0.519
Totals		0.183		0.189		0.258		0.196		0.138		0.096

EXHIBIT 15 - SUMMARY OF TASK 2

Sequence	Probability of Achieving Objective[1]					
	Encounter Science		Cruise Science		Engineering Data	All Objectives
	TV	UV	Cruise	Encounter		
Planned Sequence	0.146 (0.170)	0.152 (0.175)	0.213 (0.243)	0.171 (0.199)	0.109 (0.124)	0.077 (0.089)
Inertial roll after midcourse maneuver in event of star tracker failure	0.160 (0.186)	0.166 (0.192)	0.256[2] (0.291)	0.187 (0.217)	0.131[2] (0.148)	0.084 (0.098)
Redundant PNG/ADC equipment	0.155 (0.179)	0.160 (0.185)	0.224 (0.254)	0.181 (0.210)	0.115 (0.130)	0.084 (0.097)
CC and S and radio command in parallel after midcourse maneuver	0.176 (0.204)	0.177 (0.276)	0.228 (0.348)	0.182 (0.212)	0.117 (0.178)	(0.091) (0.105)
All alternatives	0.183	0.189	0.258	0.196	0.138	0.096

Notes: (1) Numbers in parentheses eliminate the three operational probabilities.

(2) Since the spacecraft is in free roll for 5,950 hours, this probability may not be associated with the return of all data during the entire period.

the probabilities computed without the three operational probabilities: (1) probability of not achieving a wrong target, (2) probability of an accurate maneuver, and (3) the probability that the solar panels do not degrade to the extent that the battery is needed at encounter. The use of the radio commands as a backup increases the probabilities of achieving the objectives over those of the nominal sequence. The increase is not appreciable, as discussed above, due to the low probability assessed to the radio command units. Section IV explores further implications of these probabilities.

3. CC and S Failures at Specific Times

Exhibit 16 gives the summary of the probabilities of achieving the objectives, assuming that the CC and S fails at specific times in the Planned Sequence. The probability of CC and S failure is also shown, being very small at the beginning and increasing to 0.36 at encounter.

EXHIBIT 16 - SUMMARY OF OBJECTIVE PROBABILITIES IF CONTROL IS SWITCHED TO RADIO COMMANDS AT SPECIFIC TIMES

Time of CC&S Failure	Probability CC&S Failure	Probability of Achieving Objectives					
		Encounter Science		Cruise Science		Engineering Data	All Objectives
		TV	UV	Cruise	Encounter		
t_{10}	0.008	0.054 (0.060)	0.056 (0.065)	0.072 (0.081)	0.058 (0.067)	0.040 (0.045)	0.030 (0.035)
t_{17}	0.108	0.054 (0.060)	0.056 (0.065)	0.072 (0.081)	0.058 (0.067)	0.040 (0.045)	0.030 (0.035)
t_{20}	0.202	0.048 (0.054)	0.050 (0.059)	0.065 (0.073)	0.052 (0.061)	0.034 (0.040)	0.027 (0.031)
t_{24}	0.329	0.031 (0.035)	0.031 (0.036)	0.041 (0.046)	0.031 (0.038)	0.022 (0.025)	0.017 (0.020)
t_E	0.360	0.037 (0.043)	0.034 (0.040)	0.050 (0.057)	0.051 (0.060)	0.028 (0.031)	0.021 (0.024)

Note: Numbers in parentheses eliminate the three operational probabilities.

IV. TASK 3--CONCLUSIONS AND RECOMMENDATIONS

A. Problem of Task 3

In Task 3 suggested modifications are to be developed which, if adopted, would optimize the Mariner C design relative to mission objectives, including reliability. However, suggestions will be limited to those which would increase the probability of attaining the objectives considering only catastrophic failures.

Although no specific limitations were placed on this task, there are weight and subsystem redesign problems which imply a limit on adding new equipment or changing the present equipment design. These limitations were not investigated in this study and hence several suggestions for increasing reliability may be unacceptable because of other practical problems. With this realization the suggestions have been included and the decision of practical application left to further investigation.

B. Conclusions of Task 2

The most valuable information obtained from the study is the probability of attaining encounter TV and science data, and the effect of the redundant paths on this number.

An examination of the summary table of Exhibit 15 shows that the probability of successfully attaining encounter and transmitting to earth the science information is approximately 0.15 each for the TV and science data. These values are lower than one would like to see, particularly when they do not include the DAS, science, and TV subsystems themselves. The latter three subsystems, however, operate only for the short time of encounter and hence will have high reliability numbers associated with them.

The low numbers indicate that several failures can be expected. The subsystems with the lowest reliability number have been provided with redundant paths as these are the most likely subsystems to have failures. These subsystems, and associated reliability numbers, from Exhibit 3 are the star tracker, the encoder PNG/ADC, and the CC and S.

These numbers then confirm JPL's decision to provide backups for these subsystems.

From Exhibit 15 the overall increase in reliability provided by redundancy for the three failure cases considered does not appear to be large (e. g., 16 percent for the case of the CC and S and the radio command system.) Even when all redundant paths are taken together, the increase is small. The probability of obtaining TV encounter data increases from about 0.15 without redundancy to 0.18 with all three redundant paths.

Just how much redundancy increases reliability on a subsystem basis can be obtained by examination of the numbers in Exhibits 4, 6, 8, and 10. From these exhibits and the detailed computations, the following numbers for the redundant units only are obtained.

Function	Normal Path	Redundant Path
Star tracker (S. T.)	0.79	
S. T. + inertial control		0.86
CC and S	0.63	
CC and S + command system		0.74
PNG/ADC	0.88	
with spare		0.92

In the above table the numbers apply to the primary objective of obtaining science data at encounter. The number pairs for the normal and redundant paths show the increase in reliability due to the alternate path being in parallel after midcourse maneuver. As can be seen, only small gains in reliability are obtained. This is due to the inherent reliability limitations of the radio command system, which, unfortunately, is in each of the redundant paths. This system has a reliability at encounter of about 0.39 in the redundant path. This illustrates that a redundant path with a reliability much smaller than the primary path does very little good.

If the command system could be eliminated from the redundant paths by (1) using a second star tracker system,[1] (2) providing a simplified

[1] Practical problems of failure sensing and switching logic that will need solutions are recognized.

redundant CC and S to operate the commands after midcourse correction,[1] and (3) providing automatic switching of all redundant systems internal to the spacecraft, then the numbers would become as shown in the last column below:

Function	Normal Path	Redundant Paths: With Command	Redundant Paths: Without Command
Star tracker control	0.79	0.86	0.96
CC and S	0.63	0.74	0.87
PNG/ADC	0.88	0.92	0.97

These redundant path values should be considered as first approximations only in that switching through command is not assumed; this ignores the reliability of a failure sensor and switch. Moreover, the fact that the spare may not be operating until needed is ignored. Nevertheless, the magnitude of the numbers indicates that worthwhile gains may be realized.

The PNG/ADC numbers, however, are misleading if the effect of the series circuits in the encoder is ignored. The series circuits have a reliability of about 0.55 which results in the PNG/ADC reliability with the series circuits becoming:

	Normal Path	Redundant: With Command	Redundant: Without Command
PNG/ADC with series circuits	0.48	0.51	0.60

As can be seen, even a redundancy without the command system is masked by the series circuits. Thus, either the series circuits should be redundant also or the PNG redundancy should be eliminated and the weight and power used to advantage elsewhere.

If, on the other hand, there are other reasons for concern over the PNG, the system design could be modified to operate without pseudonoise modulation as an emergency condition. This could be done automatically in the modulator design.

[1] Practical problems of failure sensing and switching logic that will need solutions are recognized.

A factor which contributes to the low reliability of the series circuits is that they must operate from launch so as to transmit the cruise science and engineering data. Hence, at encounter they already have some 6,000 or more hours of operating time. The encounter science instruments, on the other hand, are not turned on until encounter. An improvement to this situation would be to provide a separate channel of series circuits plus a spare PNG. Thus an independent path would be provided for the encounter science which need not be turned on until encounter. With two complete paths of series circuits, logic could be included so that each could act as a spare for the other. Even without this last feature, the reliability of the series circuits, including the PNG, would be increased from the present 0.48 to about 0.97 for the encounter operating time.

The solar vanes for stabilizing the spacecraft are an example of the kind of subsystem that has desirable characteristics resulting in high reliability. This subsystem has a minimum of moving parts, is solar powered, and consumes essentially zero energy when the spacecraft is nulled to the sun line. As a result, once stabilization is reached the reliability is essentially 1.0 for keeping it in the nulled position. If a disturbance occurs, such as a meteor hit, then the additional equipment necessary to restore the spacecraft to sun-line null is brought into action.

Certainly it is not possible to design all subsystems like the solar vane stabilization system; however, the general characteristics of this subsystem are of interest in a design for reliability. Some of these characteristics are:

1. Standby power and the number of equipments operating should be at a minimum when error signals or load demands are in a null condition. This implies turning off all equipment that is not needed to maintain a nulled error signal or standby condition.

2. Large error signals or load demands should be sensed to automatically activate the additional equipment needed to provide the additional action required.

3. Missions entailing intermittent operation with long periods of standby indicate the need for provisions for turning off the equipment during the standby period. In this manner the life of the equipment can be conserved for that time period when it is most urgently needed. Also time sharing of equipment needed for primary objectives by assigning it secondary objectives should be avoided if the secondary objectives use up most of the life prior to the primary objective demand.

In general, the spacecraft design has met these conditions with only a few exceptions, as previously noted.

C. Recommendations

The recommendations are based on the work of Task 2 and the above conclusions. They have been made as specific as possible with the available design information on the Mariner C. The recommendations were judged on the basis of maximizing the reliability while minimizing any hardware changes, and due to time limitations are not necessarily all inclusive. The recommendations are as follows:

1. Whenever possible switching to spare or redundant equipment should be done by simple failure sensors internal in the spacecraft rather than by radio command. This is already done in a number of equipments and could be applied to the PNG/ADC.

2. An alternate star tracker should be used to back up the Canopus tracker rather than the inertial roll and command system. The inertial roll equipment is in the vehicle for acquisition and thrust vectoring control and cannot be removed. With the long time-to-encounter, however, and the limited gyro life, only intermittent control can be provided by the inertial roll control during cruise. An alternate sensor which would be turned on with failure of the Canopus signal would be a worthwhile addition, because it eliminates the radio link in the redundant path. The failure sensing and the switching logic will require solution.

3. An alternate for the CC and S, to operate only after completion of midcourse maneuver, should be provided in the spacecraft, rather than using the radio command system. This would materially

increase the probability of reaching encounter. This could be designed to provide a redundancy only for the CC and S series circuits, since they are the low reliability part of the subsystem. A completely separate simple system, however, could be used since only a few signals are required after midcourse.[1] For example, a simple highly reliable electromechanical clock such as the Accutron could be used.

4. A separate path consisting of the series circuits and PNG in the encoder should be used for encounter science and TV--to be turned on only during encounter. This would provide a substantial increase in the probability of obtaining encounter data. Since this equipment would duplicate the series circuits and PNG required for cruise science and engineering, they could be connected switchably redundant.

The above are the principal recommendations which will increase system reliability. Several additional items, however, suggest themselves which are of less importance if the above suggestions are carried out. These suggestions are:

1. The spare PNG in the encoder could also be used as a switchable spare for the PNG in the command receiver subsystem. Similarly, the spare ADC in the encoder could be used as a spare for the ADC's in some of the science and TV instruments. However, further investigation of the reliability of required switching is necessary before this suggestion could be mechanized.

2. The PNG's are an important part of both the encoder and command system. Failure of these units could prevent the transmission of data. The equipment design should be such that operation could continue, even though degraded, with PNG failure.

3. The long flight time to encounter makes the radio command system the limiting effect on reliability of any backup which must depend upon it, including the radio system as a backup to the CC and S. As an alternate, a separate simple system using tone coding and tone-sensitive relays could be provided to be turned on by failure of the command system.

[1] These are the Canopus cone angle updating, the bit rate change, the antenna switch to high gain, and the encounter.

Such a device could operate the few commands required after midcourse correction. This would place on the line a reliable command system with an unused lifetime near encounter time.

D. Effect of Recommendations

The mechanization of the first four recommendations will have a marked effect on the probability of obtaining encounter science data. The reliability will be increased from about 0.15 to 0.48, including the operational probabilities, and from 0.17 to 0.54 for the equipment only (not including the operational probabilities).

The computations and changes suggested include:

1. A redundant star tracker operating for the full flight.

2. A redundant but simplified CC and S operating from the end of midcourse maneuver to encounter.

3. A separate encoder channel consisting of the spare PNG and the series circuits operating during encounter only.

With these recommendations the numbers from Exhibit 4 are influenced as follows:

Subsystem Affected	Present Reliability	Reliability Recommended With Change
A/C star acquisition and tracking	0.67 (0.74)[1]	
with redundant star tracker		0.81 (0.89)
CC and S	0.63	
with redundancy		0.86
Encoder to t_{29}	0.48	
Encoder during encounter only		0.97
Total System:		
Normal sequence	0.15 (0.17)	
Three present redundant paths	0.18	
With suggested changes	0.48 (0.54)	

[1] Numbers in parentheses are without operational probabilities.

The increase in reliability with the changes suggested is reflected in the numbers listed under total system, but these numbers apply only to obtaining encounter science.

The changes imply added equipment which probably rules out their application to Mariner C. It may be possible that Mariner B, however, could mechanize these or similar changes to realize the higher reliability number indicated.